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Relationship Between Jump Tests and Their Influence on Multidirectional Ground-reaction Forces in Baseball Pitchers

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**RELATIONSHIP BETWEEN JUMP TESTS AND THEIR
INFLUENCE ON MULTIDIRECTIONAL GROUND-REACTION
FORCES IN BASEBALL PITCHERS**

by

Ryan Lis, B.S.

A Thesis Presented in Partial Fulfillment
Of the Requirements for the Degree
Master of Science in Kinesiology

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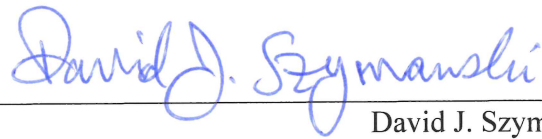
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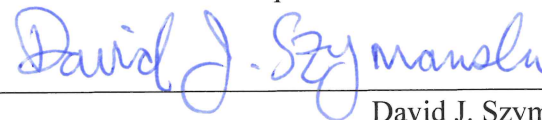
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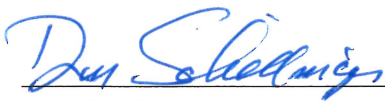
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ABSTRACT

Jump tests are effective, valid, and reliable methods to examine lower body power and possibly influence ground reaction forces (GRFs) in baseball pitching. **Purpose:** To determine relationships between drive leg and stride leg GRFs and fastball velocities while pitching from the wind-up and stretch to 1) drive leg and stride leg GRFs of unilateral countermovement jumps (UCMJ) and bilateral countermovement jumps (BCMJ), 2) BCMJ, and drive and stride leg UCMJ height as well as bilateral broad jump (BBJ) and drive and stride leg unilateral lateral to medial jump (ULMJ) distances, and 3) BBJ estimated peak power. **Methods:** Nineteen Division I collegiate baseball pitchers (age 19.9 ± 1.5 years, height $1.86 \pm .06$ m, body mass 90.7 ± 13.8 kg) completed six multi-directional jump tests and threw fastballs from a pitching mound with embedded force plates. **Results:** Three moderate and one moderately high statistically significant relationships were observed for BCMJ and UCMJ heights to pitching GRFs, $p < 0.05$. Stride leg UCMJ height was significantly greater than drive leg UCMJ height, $p < 0.01$. Wind-up and stretch GRFs were statistically similar. Fastball velocities had statistically moderately high relationships to wind-up and stretch drive leg GRFs. Fastball velocities were statistically similar between both deliveries. **Conclusion:** Collegiate pitcher's jumped higher and had more power displayed by their stride leg compared to their drive leg, and produced more power vertically when summing drive and stride leg UCMJ forces compared to BCMJ force. Both wind-up and stretch drive leg forces had moderately high associations to fastball velocities.

Keywords: *baseball pitching, fastball velocity, ground reaction forces, multi-directional jumps*

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KEY TO ABBREVIATIONS

| | |
|--------|--|
| ANOVA | Analysis of variance |
| AVCF | Average vertical concentric force |
| BBJ | Bilateral broad jump |
| BCMJ | Bilateral countermovement jump |
| BW | Body weight |
| COM | Center of mass |
| CVI | Concentric vertical impulse |
| DOF | Degrees of freedom |
| DUCMJ | Drive leg unilateral countermovement jump |
| DULMJ | Drive leg unilateral lateral to medial jump |
| EccRFD | Eccentric rate of force development |
| GRF | Ground reaction forces |
| RSImod | Reactive strength index modified |
| SULMJ | Stride leg unilateral lateral to medial jump |
| UCL | Ulnar collateral ligament |

CHAPTER 1

INTRODUCTION

Power has been suggested to be a very important factor in achieving success within sport (Coburn, 2012; Cronin & Sleivert, 2005; Haff & Nimphius, 2012; Noffal & Lynn, 2012). Producing power has been considered to be just as important, if not more important, as strength for sports (Kraemer & Looney, 2012), although some have considered strength to be of similar or greater importance for sport performance compared to power (Cronin & Sleivert, 2005). Power has been defined as the product of force and velocity (Coburn, 2012; Haff & Nimphius, 2012; Kraemer & Looney, 2012; Noffal & Lynn, 2012; Turner et al., 2020). Expression of power can be influenced by the size of the muscles recruited and the number of activated motor units, the type of muscle fibers that are associated with the recruited motor units, rate coding, myosin ATPase enzyme levels, development level of the individual's ATP-PCr (phosphagen) energy system, training history, and possibly the ability to control inhibition processes within the body (i.e. coactivation levels and Golgi tendon organs) (Kraemer & Looney, 2012).

In order for an individual to jump higher, it has been speculated that they must increase their force production, takeoff velocity, and peak power (Darmiento et al., 2012). With this increase in jump height achieved by these characteristics, it can be assumed that sport performance activities that require jumping, throwing, or change of direction (Haff & Nimphius, 2012) would improve as jumping ability and power have been correlated with sport performance (Darmiento et al., 2012). This relationship illustrates one's ability to produce greater force and/or velocity, which

would result in greater power production. These relationships and characteristics help demonstrate that power can usually be expressed as a generic neuromuscular or sport performance characteristic (Turner et al., 2020). Jumping height demonstrates an individual's ability to create power within a limited timeframe of < 0.3 seconds, which is the time frame that most athletic movements occur in sport (Turner et al., 2020). Consequently, coordinating explosive actions in a short time frame demonstrates why jump performance has been related to sport performance and therefore, could have an impact on sport-specific mechanics.

Jump testing can be an effective, valid, and reliable method to assess lower body power (Coburn, 2012), as it mimics the duration of a delivery seen within cricket, which has a similar time frame to a baseball pitch. (Freeston et al., 2016). Within this short time frame, cricket players coordinate force from their drive leg and stride leg. The drive leg is the trail leg during a throw, while the stride leg is the lead leg that braces forward momentum during the throwing motion (Ramsey & Crotin, 2019). Common jump tests that are used within sport performance are the two leg or bilateral countermovement vertical jump (BCMJ), bilateral broad jump (BBJ), single leg or unilateral countermovement vertical jump (UCMJ), and unilateral lateral to medial jump (ULMJ). A battery of two or more power tests may predict sport performance better (Cronin & Sleivert, 2005). It is important that tests assessing the same variable have some slight variation in order to achieve a well-rounded analysis of the specified variable and power applied in multiple planes of movement. A suggestion for coaches has been to pick tests that are biomechanically similar to the sport's movement patterns (Coburn, 2012). Jump tests performed on force plates give an in-depth analysis of an individual's BCMJ and UCMJ data, such as peak power, reactive strength index modified, ground reaction force (GRF), and rate of force development. These variables are potentially more relevant to sport performance than simply the jump height achieved as they are

under the pressure of time and require rapid stretch-shortening cycles (Laffaye et al., 2014; Mayberry et al., 2020; Suchomel et al., 2015). Simultaneous force plate data collection for various jump tests, such as the BCMJ and UCMJ, BBJ, and drive leg and stride leg ULMJ for multiple athletes that are completing numerous performance and anthropometric tests in a short period of testing time, would be challenging as it would require a relatively large amount of funding to purchase three to four devices to assess the athletes. Therefore, if there is only one or two force plates available and testing time is limited, those that collect this type of data will need to decide which test will use the force plate(s) and which tests will not require them. If BCMJ and UCMJ tests are selected to use force plates based on previous research, both coaching and talent identification insights may be stronger if BBJ and ULMJ can be collected even though force plate data is not collected. However, it would be interesting to record force plate data while athletes perform the BBJ and ULMJ as throwing at higher velocity may be more related to GRFs in the horizontal direction of anterior posterior versus vertical GRF profiles (Lehman et al., 2013; Ramsey & Crotin, 2019).

Force plates inserted into a custom mound for pitchers provides information about lower extremity GRFs, specifically their drive leg and their stride leg. Ground reaction force is a measure of the net vertical and shear forces that are acting over the force plate (Winter, 1988). With this information as well as three-dimensional motion capture data, pitchers who are not utilizing their lower body sufficiently can be identified. This could lead to the ability to detect any pitcher's upper extremity compensation patterns that occur to maintain ball velocity (Ramsey & Crotin, 2016). Similarly, if compensation increases load variability to the pitcher's shoulder and elbow, injury risks could be associated with less than optimal lower body power in the delivery (Trigt et al., 2020).

To the author's knowledge, there is no specific and agreed upon test that helps coaches and sport performance staff identify pitchers who can efficiently use their lower body to produce force during pitching. Therefore, the purposes of this study are to determine relationships between drive leg and stride leg GRFs and fastball velocities while pitching from the wind-up and stretch to 1) drive leg and stride leg GRFs of UCMJ and BCMJ, 2) BCMJ and drive leg and stride leg UCMJ height as well as BBJ and drive leg and stride leg ULMJ distances, and 3) BBJ estimated peak power. For the first aim, it is hypothesized that pitchers who demonstrate higher GRFs in the drive leg and stride leg UCMJ and BCMJ tests will show higher GRFs and fastball velocities during their pitching deliveries. For the second aim, it is hypothesized that pitchers who jump higher for the drive and stride leg UCMJ and BCMJ and jump farther for the BBJ and drive and stride leg ULMJ will show higher GRFs and fastball velocities during their pitching deliveries. For the third aim, it is hypothesized that pitchers who have the higher estimated peak power from the BBJ will show higher GRFs and fastball velocities during their pitching deliveries.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Overview

A baseball pitcher can experience up to 43 Nm of stress on their ulnar collateral ligament (UCL), which is above the recorded values seen within cadavers (Cohen et al., 2019). Pitchers also have an injury rate that is 34% more than infielders (Posner et al., 2011) and pitchers have been shown to represent 56.9% of the total number of disabled list days (Conte et al., 2001). Conte et al. (2001) has stated that it is a reasonable assumption that better training methods, diagnostic equipment, and surgical treatments have improved over the past couple of decades. However, there is still an observed increase in injury rates and number of days spent on the disabled list. Pitchers within professional baseball that threw at higher velocities were significantly more at risk of having an elbow injury, but also had significantly longer careers than pitchers that threw slower (Bushnell et al., 2010). Pitchers that threw with higher velocity are viewed as more valuable to the baseball club, thus allowing them to have a relatively longer career. Therefore, a risk-reward ratio exists as velocity is a coveted attribute by baseball scouts, general managers, and coaches, but also a clear risk factor. A UCL tear will inhibit a pitcher from being able to contribute to the team's success for an entire season, therefore it is important for pitchers to learn how to use their body by creating an efficient kinetic chain that optimizes the transfer of force from large muscles of the legs to the core muscles of the torso to the throwing hand (Kibler et al., 2013; Kibler & Sciascia,

2004). There has been research looking at correlations of jump tests to injuries within professional baseball pitchers that may shed some light on how stretch-shortening responses coordinated by the lower body may manifest in overload for the UCL (Mayberry et al., 2020). However, no research has compared GRFs produced within jump tests to the GRFs seen within a pitcher's delivery. Through understanding the connection between jump performance, and propulsion and braking GRFs in pitching, a more direct relationship to elbow health may emerge, as UCL injuries occur during the act of pitching and not jumping. More research is required to strengthen the evidence associating GRFs in jumping to GRF observations during the pitching delivery that may lead to future advancement in health and performance in baseball.

2.2 Pitching Ground Reaction Forces

As a baseball pitcher is delivering a pitch toward home plate, his lower body is producing forces with either the drive leg or stride leg to deliver the ball. Ground reaction forces were seen to be concentrated within the intended path of the throw (MacWilliams et al., 1998). MacWilliams et al. (1998) also found that GRFs are highly repeatable, therefore assessing a pitcher's GRFs from several pitches is reliable. By having two force plates within a pitching delivery, feedback about the GRFs developed within the drive leg or stride leg can be captured. Ground reaction forces within pitching completed on force plates is divided into three coordinate systems; x-axis (anterior posterior axis) which is directed towards home plate, the y-axis (medial lateral axis) is positioned towards first base for a right-handed pitcher, and the z-axis (vertical axis) is the vertical system. With this information coaches and performance staff are able to understand the ability of the pitcher to express GRFs within their lower body throughout their pitching delivery. Through vertical jump comparisons from the delivery to the UCMJ and BCMJ GRFs, coaches and clinical

staff may be able to accurately identify pitchers who are not using their lower body efficiently throughout their kinetic chain while pitching.

2.2.1 Drive Leg

There seems to be a weak correlation of ball speed to peak resultant force and vertical force during peak anterior force of the drive leg (Oyama & Myers, 2017). Stride leg and drive leg GRFs combined together allows measurement of energy flow and indicates that both limbs are important for transferring power throughout the entire kinetic chain within the pitching delivery (Howenstein et al., 2020). Stride length for the pitcher can play a role in determining the amount of drive leg propulsion and posterior shear breaking forces that are demonstrated during pitching (Ramsey & Crotin, 2019). A longer stride demonstrated greater drive leg propulsion and posterior shear breaking forces, while a shorter stride had less drive leg propulsion and breaking forces (Ramsey & Crotin, 2019). Campbell et al. (2010) found that electromyograph (EMG) data of the gluteus maximus, gastrocnemius, rectus femoris, vastus lateralis, and biceps femoris had the highest activation levels for the drive leg of pitchers during stride foot contact to ball release. This illustrates the production of energy via the lower body prior to ball release. Specifically, the vastus medialis, biceps femoris, and gluteus maximus were considered to be contributors for stabilizing and controlling the lower body. If there is inadequate muscle activation within the lower extremities, the kinetic chain could be weakened, thus limiting the amount of force and corresponding linear energy produced from the lower body prior to bracing. As a result, less than optimal linear energy could reduce bracing effort and subsequent transfer of linear to rotational energy.

2.2.2 Stride Leg

Stride leg GRFs within the vertical and posterior directions and the resultant GRFs for peak wrist velocity during the arm-cocking and arm-acceleration phase were strongly correlated (McNally et al., 2015). Strength of the stride leg muscle, specifically the rectus femoris, has been shown to play an important role within professional and collegiate pitchers that were able to throw at higher velocities than other pitchers within the same study (Matsuo et al., 2001). These authors suggested that the strength of the stride leg helps with bracing forces that should contribute to a greater transfer of force to help create maximal pitching velocities. Another muscle to focus on within the stride leg is the vastus medialis, which had a gradual increase in EMG activation within pitching and saw the highest EMG activation during stride foot contact to ball release (Campbell et al., 2010). This EMG activation of the vastus medialis indicates its role stabilizing the knee joint throughout a pitch. Therefore, it can be assumed that with better stability of the stride leg, the force transmitted through the kinetic chain will help transfer energy to the distal parts of the body.

2.2.3 Section Summary

Ground reaction forces seen within pitching deliveries are consistent and important contributors to the kinetic chain for distributing the forces throughout the body, and theoretically can make pitchers more efficient in delivering a baseball at high velocities with lower relative shoulder and elbow joint loads (Howenstein et al., 2019).

2.3 Jump Performance

Mayberry et al. (2020) highlights the possibility of analyzing jumping variables to predict a pitcher's chance of injury through evaluating eccentric rate of force development (EccRFD), average vertical concentric force (AVCF), and concentric vertical impulse (CVI). All variables were significant in predicting elbow injury within 274 professional baseball players. There was a heightened risk when the results showed a low EccRFD, a low AVCF paired with a high CVI, or a high AVCF paired with a low CVI. Eccentric rate of force development does have evidence as a good predictor for VJ height within professional baseball players (Laffaye & Wagner, 2013), while there is also evidence of professional baseball players having a more explosive profile that creates greater relative EccRFD and AVCF compared to basketball and volleyball players (Laffaye et al., 2014). Therefore, it is important to assess these variables when conducting jump tests. Vertical jump performance has also been shown to decrease significantly as professional players age into their 30's specifically within pitchers (Mangine et al., 2013). However, to the author's knowledge, there are no studies looking at the relationships of pitcher's age, injury rates, and decline in vertical jump power.

2.3.1 *Unilateral Lateral to Medial Jump*

The ULMJ test is very specific to the sport of baseball as it mimics the frontal plane propulsion required of the drive leg in pitching (Freeston et al., 2016; Lehman et al., 2013). A study assessing college-level baseball players from two teams using several lower body field tests found that ULMJ of the drive leg was the best predictor of ball speed thrown from flat ground (Lehman et al., 2013). Therefore, based on this study, it was thought by the current author that pitchers who demonstrate greater distances achieved within the ULMJ test might

have greater GRFs in their drive leg and higher fastball velocities during their pitching deliveries from a pitching mound. A further analysis of the ULMJ, specifically the action of stride leg isometric hip abduction strength which involves the gluteus medius muscle, had a significant relationship to throwing speed within cricket players (Ahmed et al., 2020). Furthermore, Freeston et al. (2016) did find a significant relationship between drive leg ULMJ and throwing velocity from the stretch within cricket players. On the other hand, Szymanski et al. (2020) did not find a significant relationship between drive leg or stride leg ULMJ and fastball velocity in Division I collegiate baseball pitchers from the wind-up or stretch from a pitching mound. Both cricket articles did mention that it is not ideal to compare cricket players to baseball players, as the style of throwing and the anthropometric features between them differ. Pitchers have weaker gluteus medius strength levels compared to position players through evaluating isometric hip abduction strength (Laudner et al., 2010). This could indicate that pitchers are compensating for their lower body abduction strength by having more force stressed at their upper extremity, or perhaps utilizing more elasticity through range of motion at the shoulder. This study did mention that there is a possibility of no clinical significance and the authors believed their findings were due to position players performing fielding and hitting motions that require a greater degree of hip abduction. A review article by Kibler et al. (2013) reported that having weak hip abductors is considered to play a role in disturbing the transfer of force through the kinetic chain, thus making the upper extremities exposed to more stress that could eventually lead to an injury.

2.3.2 Bilateral Broad Jump

The BBJ is another lower body power test that demonstrates an individual's ability to produce force in the intended anterior direction. Broad jump has reached a level of significance

for predicting pitching velocity within 46 young teenagers (Nakata et al., 2013). Two studies have also found a significant relationship between BBJ and throwing velocity within young male and female handball players (Zapartidis et al., 2009, 2011). Lehman et al. (2013) and Szymanski et al. (2020) have presented contradictory evidence, as they did not find a relationship between BBJ and throwing velocity within college-level baseball players from flat ground or fastball velocity from the wind-up and stretch with Division I collegiate pitchers.

2.3.3 Bilateral Countermovement Jump

Bilateral countermovement jump mean and peak power has been reported to be significantly greater within Major League Baseball players compared to minor league levels (Hoffman et al., 2009); however, this study did not report pitching velocity values. There is contradicting evidence for BCMJ and throwing and pitching velocity. Lehman et al. (2013) and Szymanski et al. (2020) found no significant correlation between BCMJ performance and throwing velocity within college-level baseball players throwing from flat ground or fastball velocity from the wind-up and stretch within Division I collegiate baseball pitchers throwing from a mound. Freeston et al. (2016) found that BCMJ within cricket players did not have any relationship to throwing velocity from the stretch position and mentioned that exercises of greater movement specificity (i.e., ULMJ) would be better predictors than exercises with less movement specificity (i.e., BCMJ). Donahue et al. (2020) found no significant difference of BCMJ between professional starters and relievers, which lead the authors to conclude that these specific positions within baseball could train similarly. Vertical jump and pitching velocity within professional players also exhibited no significant relationship (Donahue et al., 2018). A UCMJ can help indicate differences between an individual's drive and stride leg power, and possibly demonstrate the contribution of

either the drive leg or stride leg within a pitching delivery. Szymanski et al. (2020) did not find a significant relationship between drive leg or stride leg UCMJ and fastball velocity within Division I collegiate pitchers throwing from the wind-up and stretch from a mound. However, more research is warranted to possibly find a relationship of UCMJ GRFs and unilateral GRFs in a pitching delivery.

2.3.4 Section Summary

Jump testing is quick, accurate, reliable, and has demonstrated movement efficiency of the lower body (Nibali et al., 2015), yet in order to truly understand the force properties, teams/colleges would require expensive force plates and trained staff to analyze the data. In addition to the BCMJ, the ULMJ, BBJ, and UCMJ are jump tests that should be considered when looking for talent identification. Although there is a limited amount of literature on ULMJ, BBJ, and UCMJ and pitching performance, further research is required to understand any possible relationships.

2.4 Factors that Influence Bilateral Countermovement Jump Performance

There are several factors, such as gender, muscle characteristics/fiber type, technique of jumping, neuromuscular considerations, anthropometry, type of training, and sport background, that can determine how high an individual will be able to jump. Therefore, several factors discussed below provide evidence as to why certain individuals are able to jump higher than others.

2.4.1 Gender

A vast majority of research has demonstrated that males can jump higher than females. There are also some variables associated with the gender of the individual, and those variables

can play a role with jump performance. The sections that follow gender, such as muscle characteristics/fiber type, anthropometry, neuromuscular considerations, and sport background, can also demonstrate why males are able to achieve a greater BCMJ than females. According to Abidin and Adam (2013), males had significantly greater BCMJ height than females within elite martial art athletes. These authors also found a negative association between a skinfold body fat percentage test and BCMJ height, which could have influenced the gender difference as males typically have lower body fat percentage than females. Body fat percentage measured via BodPod has also been shown to be a significant predictor for BCMJ height within recreational male athletes (Davis et al., 2003). A significant difference was observed for recreationally active participant's BCMJ for males compared to females (Márquez et al., 2017; Smith et al., 2020). A significant gender difference in jump height was also observed with ballet dancers, with males jumping higher (Wyon et al., 2006). Suchomel et al. (2015) found that Division I men's soccer and baseball teams had significantly greater BCMJ heights than women's soccer and tennis, while only the baseball team reached significance for BCMJ height compared to female volleyball players. There was another significant difference in jump height between athletic men compared to women (McMahon et al., 2017). Each gender belonged to a different sport and the authors mentioned that they might have a different strategy to jump, which could have resulted in limiting their BCMJ height. Smith et al. (2020) have suggested that men may be able to utilize the stretch shortening cycle better than females as negative joint power and work were similar. Ham et al. (2007) stated that reactive strength can add to the concentric action during takeoff by increasing power production which will increase jump height.

2.4.2 Muscle Characteristics/Fiber Type

High BCMJ achievement is predominantly accomplished by fast twitch fiber recruitment (Ham et al., 2007). Muscle cross-sectional area of the vastus lateralis and total knee extensors revealed women having 30 and 45% smaller cross-sectional area compared to men, respectively, that could be owed to lower jump heights by females (Miller et al., 1993). Authors also noted that females had a significantly greater amount of non-contractile tissue within the vastus lateralis compared to men, which would not contribute to greater force production of the lower body. In terms of type II fibers (fast twitch), men had a significantly higher proportion of type II within the vastus lateralis and demonstrated significantly larger type I and type II fibers compared to females. This fiber type advantage of the vastus lateralis muscle does not seem to carry over into BCMJ performance as the vastus lateralis had no significant correlations of fascicle thickness, fascicle length, and pennation angle (Earp et al., 2010). However, Secomb et al. (2015) did find that vastus lateralis thickness was significantly related to greater jumping performance. Other research has shown lateral gastrocnemius thickness and pennation angle to be significantly related to jump performance (Earp et al., 2010; Secomb et al., 2015).

2.4.3 Methods of Jumping

Vertical jump technique used in research varies, with some studies allowing participants to use their arms in preparing the countermovement aspect before taking off in a jump. Some studies have tried to limit the amount of influence an arm swing and countermovement has on the vertical jump as not every participant knows how to properly utilize these variables (Donahue et al., 2018, 2020; Earp et al., 2010; Secomb et al., 2015; Sozbir, 2016). The use of arms to assist with attaining maximal jumping height was shown to increase take-off velocity on average by 10% for a

countermovement or no-countermovement jump (Harman et al., 1990). These authors also found that the use of a countermovement had a 3% increase in overall vertical ground reaction impulse, and it has been widely acknowledged that arm swings do increase vertical ground reaction impulse (Ham et al., 2007). A common procedure that researchers include is a familiarization session with the participants of the study. Therefore, the learning effect does not occur during data collection, thus ruling out the possibility of outliers or false data. Nibalia et al. (2015) did find that familiarization trials before a vertical jump test were not required in athletes regardless of level of play or sport. An explanation that the authors stated was that the vertical jump performance improvement with familiarization does not really exist within athletes as it replicates movements seen within their sport. Athletes already have the coordination of their body to perform the movement on a consistent basis. Another method that is used within the literature for jump tests is having each subject use the same kind of shoe. An evaluation of differences between a standard shoe and a minimalist shoe was not observed for vertical jump within recreationally trained college students (Smith et al., 2020). Although the authors did mention a limitation of application towards elite athletes as they might have a different response using different shoes for their vertical jump.

2.4.4 Neuromuscular Considerations

One of the most important factors to increase the force produced during a BCMJ is by having the muscles optimize their firing patterns (Ham et al., 2007). Nagano and Gerritsen (2001) did find within a 2-D skeletal model that an interaction effect of maximum isometric force, maximal concentric velocity, and maximal motor unit recruitment had a greater increase in BCMJ height than the sum of all the previous factors individually. Márquez et al. (2017) found significantly greater EMG activation of the rectus femoris and tibialis posterior during the

landing phase and only the rectus femoris during the concentric phase of the jump within men. In contrast, Miller et al. (1993) found no significant difference between men being able to activate more motor units than females within the knee extensors. A member of the knee extensor muscle group is the rectus femoris. This muscle group has demonstrated within a 2-D skeletal model to be the most important lower body musculature for increasing jump performance (Nagano & Gerritsen, 2001). Females within the Márquez study did demonstrate significantly greater muscle co-activation levels of the lower body during the concentric part and lower co-activation levels for the landing part of a jump. Greater co-activation levels during the concentric part would cause a decrease in total power output (Kraemer & Looney, 2012).

2.4.5 Anthropometry

The anthropometry of an individual can have some influence within a jump. Thigh and calf circumference were significant predictors for BCMJ in ballet dancers (Wyon et al., 2006). Another study that looked at recreational male athletes found that only right calf girth significantly predicted BCMJ height (Davis et al., 2003); a theory that the authors discussed about was that the greater calf girth could be related to cross sectional area of the muscle or the amount of body fat within the calf. Davis et al. (2003) also found that as age increased within their participants their BCMJ also increased significantly within an age range of 20–37-year-old participants. Mangine et al. (2013) saw an increase of lean body mass and BCMJ until the age of 29 years, which demonstrates the possibility to increase lean body mass and BCMJ together, yet optimums within baseball players have not been examined. Professional starting pitchers had a significant difference for height compared to relief pitchers (Donahue et al., 2020). This

significant difference observed for stature did not have a level of significance for the BCMJ test between starters and relievers.

2.4.6 Type of Training

Individuals do have the ability to increase their BCMJ by certain types of training. Elite adolescent handball players who were randomly assigned to a plyometric training program had a significant increase in BCMJ height compared to those players that were in a control (Chelly et al., 2014). Vertical jump height significantly increased within untrained youths compared to young trained basketball players (Verma et al., 2015). A statement by the authors was that the trained individuals already had the neuromuscular adaptations that occur with plyometric training, which is what caused the significant difference for the untrained group. Wyon et al. (2006) found that male ballet dancers resistance trained significantly more than females, but resistance trained males did not have significantly greater BCMJ height than those who did not train. A comment by the authors was that the way these ballet dancers trained was possibly not focused on increasing their BCMJ. A traditional and common type of training used within the sport of baseball, especially for starting pitchers, is to go on long distance runs the day after a game or during practice. With this type of conditioning, a concurrent interference effect could occur and cause a decrease in power production. A study conducted on collegiate baseball pitchers in-season found that sprints for conditioning had a significant difference for lower body power compared to a continuous form of conditioning (Rhea et al., 2008). A 2% average drop for power, as determined by the BCMJ, was observed for the continuous group, while the sprint group saw a 15% average increase in BCMJ height.

2.4.7 Sport Background

A comparison amongst Division I collegiate athletes of six sport teams (men's & women's soccer, men's & women's tennis, baseball, and women's volleyball) demonstrated baseball players having statistically significant values for reactive strength index modified and BCMJ in an unloaded condition compared to men's and women's tennis and women's soccer. While in the loaded condition (20 kg), values for the previous teams and the women's volleyball team reached a significant difference of reactive strength index modified and BCMJ (Suchomel et al., 2015). It is important to understand where the average is for collegiate baseball player's BCMJ and BBJ, as this information can inform coaches where to focus training efforts. It has been reported that an average BCMJ of 34 Division I collegiate baseball players is 27 inches while their BBJ is 96.3 inches (Spaniol, 2009). Spaniol states that BCMJ and BBJ performance increase as the competition level increases from high school to NAIA to NCAA Division I. Mangine et al. (2013) did find a significant difference for a lower BCMJ within professional baseball players in their 30's. A significant decrease of 6.3% was seen between players age groups of 29-31 and 23-25, while an 11.3% decrease was significantly observed for players >35 and 26-28. An important note is the authors stated that these differences are primarily occurring in pitchers, while position players are able to maintain their BCMJ performance.

2.4.8 Section Summary

There are several factors that influence jump performance. Men attain greater BCMJ heights than females. Type II fibers play a role within BCMJ as it is an explosive movement, and the neuromuscular system does have a role to produce high rates of force and therein, take-off velocity, as muscle fiber type differences between genders may be a determining factor owed to

gender differences. Calf girth and age of the participants are important to jump performance as tertiary factors. Plyometric training, when done properly and given a sufficient duration, can improve BCMJ within a wide array of athletic backgrounds. Within Division I collegiate athletes, baseball players were able to demonstrate significantly greater reactive strength index modified and BCMJ values compared to other Division I athletes, which is unexpected as baseball rarely involves jumping plays. Division I collegiate baseball players reveal an average BCMJ of 27 inches and a BBJ of 96.3 inches. It is important to note that the way players are trained can have an influence on their ability to produce lower body power that could be related to pitching velocity. Sport performance staff need to consider that the type of training they are requiring their players to complete will not interfere with their power production.

2.5 Overall Summary

Ground reaction force profiles produced during a UCMJ and BCMJ can help coaches and sport performance staff identify whether their pitchers are producing enough GRFs through simple neuromuscular tasks and if deficient, such discrepancies should be remediated to enhance performance in the pitching delivery. Plyometric programs are an effective means to enhance jump properties. Strength coaches should be encouraged to integrate plyometrics in companion to traditional resistance training programs to ensure that pitchers impart greater rates of force throughout the kinetic chain, theoretically reducing UCL stress. Modified reactive strength indices are a good way to assess coordination and ability for BCMJ tests and can serve as an important monitoring criteria to determine advancement in ballistic training to be more velocity or load-based and mitigate potential harmful effects of non-compatibility training (Suchomel et al., 2015). Lastly, incorporating jump tests that mirror primary baseball pitching GRF vectors,

such as the BBJ and ULMJ, could be more consequential to the delivery, and thus, incorporating them in workouts could be beneficial in advancing kinetic chain energy transfers.

CHAPTER 3

METHODS

3.1 Participants

Nineteen Division I collegiate baseball pitchers (15 right-handed and 4 left-handed: age 19.9 ± 1.5 years; height 1.86 ± 0.06 m; body mass 90.7 ± 13.8 kg) participated in this study. Each participant signed an informed consent approved by Louisiana Tech University's institutional review board. Exclusion criteria included any kind of significant injury or currently within the rehab process from a previous injury during time of testing. All tests were performed indoors of the Human Performance Laboratories at Louisiana Tech University.

3.2 Experimental Design

The tests were split up into two segments, GRFs during pitching and jump tests. For the pitching tests, GRFs were recorded during the delivery of a 4-seam fastball from the stretch and from the wind-up on a custom-built mound with force plates embedded in it. Pitches that were included within the collection of data were required to be strikes, which was recorded by a ball tracking device (Pitching 2.0, Rapsodo, Missouri, USA). Pitchers completed a standardized rotator cuff warm-up and then completed their own warm-ups prior to throwing in the lab. A minimum of 5 strikes was required by each participant to complete their data collection. Fastball velocity was calculated by using the median of the 5 pitches that were recorded and was used to

represent participants' pitching data. There were minimal differences between median and mean values and would not have impacted the *p*-values. A custom-built pitching mound had two force plates embedded in it to record the GRFs for the drive leg and stride leg.

For this study, a total of six jump tests were conducted in the Sport and Movement Science Laboratory: BCMJ, drive leg UCMJ (DUCMJ), stride leg UCMJ (SUCMJ), drive leg ULMJ (DULMJ), stride leg ULMJ (SULMJ), and BBJ. Each participant completed two familiarization sessions separated by 48 hours the week prior to testing. Ground reaction forces were recorded during the BCMJ, DUCMJ, and SUCMJ with each foot being on a separate embedded force plate for the BCMJ, while the UCMJ was performed with only one foot on one force plate. A Vertec jump testing device (Vertec Jump Measuring Device, Rogue Fitness HQ, Ohio, USA) was used to measure total jump height within each vertical jump test. Participants completed a standardized active, dynamic warm-up that included plyometric jumping exercises prior to the recording of their jump data. Jump test movements were a part of the plyometric warm-up exercises. Each jump test required participants to complete 3 trials with the best trial being reported and analyzed. If a subject achieved their best result on their last trial, they were able to complete another trial until they were unable to improve or tie their previous best attempt. A rest time of 1 minute was allowed between each trial for each jump test. Unilateral lateral to medial jump and BBJ were measured by a tape measure. For the ULMJ, the distance was recorded from the outside edge of the foot closest to the starting line, while the BBJ was measured from the participant's heel from where they landed.

3.3 Data Collection

3.3.1 Instruments and Data Collection

Two force plates (600×900 mm, model 6090-15, Bertec Corp., Columbus, OH, USA) recorded GRFs from each leg at 1040 Hz during the pitching and the BCMJ tests. One force plate recorded GRFs from each leg at 1040 Hz for the UCMJ tests.

Bilateral countermovement vertical jump and UCMJ tests were conducted by having the participant first measure their standing reach height. This was done by having each participant reach as high as they could with their dominant arm and then walk forward to push the Vertec vanes with their fingers of their dominant hand. The highest reach was measured and recorded. After their reach was established, participants conducted their three BCMJ trials and the height achieved from reach was subtracted from their highest jump. A Vertec jump device was used as an external motivator to help give a sense of visual feedback for the participants to achieve their maximum jump height. Standing reach attained from each participant was used for the UCMJ test as well, and participants were required to stand on one leg prior to their jump trial and coordinated a countermovement jump on one leg. Kinematic and kinetic data of the BCMJ and UCMJ was recorded from the beginning of the jump until landing after the jump. Thresholds for takeoff and landing were determined when vertical GRFs decreased/increased to a value of 2 N.

3.3.2 Inverse Kinematics and Dynamics

Inverse kinematics and dynamics were calculated using a 15-segment, 40-degree of freedom (DOF) human model (Qiao, 2021). Segments are the upper and lower torsos, head, hands, feet, upper/lower arms, and legs. Upper and lower torso were connected by a ball-and-socket joint with three DOFs; Shoulders, hips, neck, and wrists are ball-and-socket joints; elbows and knees are

hinges; ankles have plantar-flexion/extension, inversion/eversion, internal/external rotation; the upper body has another three translational coordinates and three Euler angles in the order of roll, pitch, and rotation relative to the global reference. Anthropometric parameters, *i.e.*, the mass, moments of inertia, COM for each body segment, and the joint location, were determined by allometric scaling of a reference human model (Huston & Passerello, 1982).

Joint angles at each time sample were calculated by using inverse kinematics. Inverse kinematics algorithm iteratively searched for joint angles that minimized a cost function (*i.e.*, the sum of squares of the differences between measured markers and markers calculated from joint angles) (Qiao & Jindrich, 2016). For inverse dynamics, the time series of joint angles were filtered with a 4th-order zero-lag low-pass Butterworth digital filter at 11 Hz and differentiated to calculate the angular velocities and accelerations. GRFs and moments from the force plates were low pass filtered at 60 Hz. Net mechanical moments of force ($M(t)_{joint}$) for all joints were calculated using Kane's method (Huston & Passerello, 1982). Joint mechanical power ($P(t)_{joint}$) was calculated as the dot product of instantaneous joint angular velocity and moment vectors. Integrating $P(t)_{joint}$ during the landing or takeoff gave the mechanical work. Position of the whole body's COM was calculated as a weighted average of the COM of each body segment. Magnitude (v) and direction (θ) of COM velocity at the instants of landing and takeoff were calculated. The reported time series of joint angle, moment, and mechanical power are both sides' average.

3.3.3 Variable Calculations

When assessing pitching force plate data during the wind-up and stretch deliveries the variables that were assessed was the velocity of the fastball, peak propulsion acceleration within

the anterior-posterior direction, GRFs of the anterior posterior, mediolateral, and vertical planes of the drive leg and stride leg.

Variables for the BCMJ that were investigated within this study were absolute peak force, normalized peak force, GRFs of the anterior posterior, mediolateral, and vertical planes, eccentric rate of force development (EccRFD), concentric impulse, takeoff velocity, and reactive strength index modified (RSImod). Table 3-1 shows all of the variables and their formulas.

Jump kinetics variables of interest during the UCMJ were absolute peak force, normalized peak force, GRFs of the anterior posterior, mediolateral, and vertical planes for the drive and stride leg, EccRFD, concentric impulse, takeoff velocity, and RSImod. A bilateral index % equation (Bogdanis et al., 2019) was used to indicate if the pitcher has greater magnitudes in jump measures on two legs versus the sum of each leg in a jump profile.

The BBJ and ULMJ were measured by total distance. Bilateral broad jump estimated peak power was calculated by using a formula that has been used in recreationally active males (DuBois et al., 2012). A stride leg and drive leg discrepancy equation will be used for the ULMJ.

Table 3-1: Variables for jump trials.

| Variable: | Formula: |
|---|--|
| RSImod ($\text{m}\cdot\text{s}^{-1}$) | Jump height/contraction time (i.e., duration from the start of the jump to take off) |
| Bilateral Index (%) | $\left(100 \times \frac{\text{bilateral measurement}}{\text{right} + \text{left unilateral measurement}}\right) - 100$ |
| DuBois P (BBJ Power Equation) | $(15.56 \times \text{distance (cm)}) - 2223.79$ |
| Drive leg and stride leg discrepancy (ULMJ) | $\frac{\text{stride leg distance} - \text{drive leg distance}}{\text{stride leg distance} + \text{drive leg distance}}$ |
| Eccentric RFD ($\text{N}\cdot\text{s}^{-1}$) | $\Delta\text{GRF} / \text{Time taken from the start of the movement to the bottom position where COM reaches its lowest point and is at 0 velocity}$ |
| Concentric Impulse ($\text{N}\cdot\text{s}^{-1}$) | $\Delta\text{GRF} \times \text{Time taken from the bottom position to take off}$ |
| Take off velocity ($\text{m}\cdot\text{s}^{-1}$) | Vertical velocity of COM at take off |
| Absolute peak power (W) | Peak from force \times velocity |
| Normalized peak power ($\text{W}\cdot\text{N}^{-1}$) | Absolute peak power / Body mass |
| Peak propulsion acceleration ($\text{m}\cdot\text{s}^{-2}$) | Peak anterior posterior GRFs / Body mass |
| Peak GRFz | Peak ground reaction force ($F = ma$) along the vertical axis |
| Normalized Peak GRFz | Peak ground reaction force along the vertical axis expressed as a percentage of body weight |

3.4 Statistical Analysis

Paired *t*-tests were used to compare the following: 1) ULMJ asymmetries between legs, 2) force summation of DUCMJ and SUCMJ compared to BCMJ, 3) peak propulsive acceleration of the wind-up to the stretch, and (4) wind-up fastball velocity to stretch fastball velocity. Seven repeated measures ANOVA were completed for comparing BCMJ, DUCMJ, and SUCMJ: 1) jump height, 2) EccRFD, 3) absolute peak power, 4) normalized peak power by bodyweight, 5) vertical takeoff velocity, 6) concentric impulse, and 7) RSImod. A Bonferroni correction and accompanied *post-hoc* tests were used when main effects were identified.

A test re-test reliability (ICC, 3, k) was used for the ULMJ as it was tested on two separate occasions (Koo & Li, 2016; McGraw & Wong, 1996), and the best distance recorded was used for the statistical analysis.

Pearson correlations (r) were used to assess the relationship between BCMJ and the UCMJ to wind-up and stretch GRFs. A separate correlation matrix was created to find associations between wind-up and stretch GRFs within the anterior posterior plane and fastball velocities compared to the six jump tests that were conducted within this study.

Cohen's d effect sizes were calculated using a pooled standard deviation. Magnitudes of effect size were scaled as follows; trivial (< 0.19), small ($0.2 \sim 0.49$), moderate ($0.5 \sim 0.79$) and large (> 0.8).

All calculations were performed using MATLAB (MathWorks[®], Inc., Natick, MA, USA). Statistical comparisons assumed an a priori alpha level of 0.05. All values are represented as mean \pm SD.

CHAPTER 4

RESULTS

Jump height achieved within the BCMJ ($0.642 \pm .09$ m) was significantly different ($p < .001$) when compared to both DUCMJ ($0.422 \pm .08$ m) and SUCMJ ($0.463 \pm .07$ m) height with large effect sizes ($d = 2.58$ and $d = 2.22$, respectively). Stride leg UCMJ compared to DUCMJ was significantly greater with a moderate effect size ($p < 0.01$, $d = .55$). Figure 4-1 illustrates the differences seen between these variables. The total amount of force produced in the BCMJ ($2.57 \pm .36$ BW) compared to the summation of the SUCMJ and DUCMJ ($4.65 \pm .56$ BW) forces equated to a $p < 0.001$ with a large effect size ($d = 4.42$). Figure 4-2 provides a further analysis of these variables. Using the formula provided by Bogdanis et al. (2019) for bilateral index (%) demonstrated a mean difference of $-27.24 \pm 4.63\%$ between their drive and stride leg UCMJ.

Comparing the drive leg ($2.09 \pm .18$ m) and stride leg ($2.09 \pm .16$ m) ULMJ revealed no significant differences and a trivial effect size in distance achieved ($p = .95$, $d = 0$). Unilateral lateral to medial jump discrepancy between a player's drive leg and stride leg revealed a mean value of 0.00 with a SD of 0.02. Bilateral broad jump values revealed a mean power of 2037.8 W with a SD of 364.76 W.

Bilateral countermovement vertical jump absolute peak power (W) (6768.94 ± 1357.57 W), peak power normalized by body weight (W/kg) (7.67 ± 1.35 W/kg), and vertical takeoff velocity ($\text{m} \cdot \text{s}^{-1}$) (2.49 ± 0.42 $\text{m} \cdot \text{s}^{-1}$) achieved a $p < 0.001$ when compared to SUCMJ ($4191.48 \pm$

681.86 W, 4.74 ± 0.6 W/kg, 1.86 ± 0.31 m·s⁻¹ respectively) and DUCMJ (3819.90 ± 723.63 W, 4.34 ± 0.75 W/kg, 1.79 ± 0.35 m·s⁻¹ respectively). Effect sizes for BCMJ were large for absolute peak power, peak power normalized by body weight, and vertical takeoff velocity when compared to SUCMJ ($d = 2.40$, $d = 2.80$, and $d = 1.71$ respectively) and the DUCMJ ($d = 2.70$, $d = 3.05$, and $d = 1.81$ respectively). Stride leg UCMJ did achieve significance of $p < 0.01$ and a moderate effect size for absolute peak power and peak power normalized by body weight when compared to the DUCMJ ($d = .53$ and $d = .59$, respectively). Vertical takeoff velocity had a small effect size and did not achieve significance between these two variables ($p = 0.22$, $d = .21$).

Concentric impulse (N·s) revealed a significance of $p < 0.05$ for BCMJ (-593 ± 192 N·s) compared to SUCMJ (-527 ± 138 N·s) and DUCMJ (-533 ± 111 N·s). No significance was found between the SUCMJ and DUCMJ ($p = 0.69$). Reactive strength index modified of the BCMJ (1.18 ± 0.4 m·s⁻¹) showed no significant differences when compared to the SUCMJ (1.27 ± 0.39 m·s⁻¹) and DUCMJ (1.36 ± 0.41 m·s⁻¹), with $p = 0.06$ and $p = 0.17$ respectively. Between the SUCMJ and DUCMJ, non-significance ($p = 0.34$) was found for RSImod. Effect sizes were small for concentric impulse and RSImod of the BCMJ to the SUCMJ ($d = .39$ and $d = .23$ respectively) and the DUCMJ ($d = .38$ and $d = .44$ respectively). Concentric impulse and RSImod did not attain significance between the drive and stride leg UCMJ ($p = 0.69$ and $p = 0.34$, respectively). A trivial effect size was observed between concentric impulse of the SUCMJ and DUCMJ ($d = .05$) and a small effect size for RSImod ($d = .22$). Peak propulsion acceleration (m·s⁻¹) within the anterior posterior direction failed to reach significance and had a small effect size ($p = 0.24$, $d = .32$) between the stretch (6.09 ± 0.32 m·s⁻¹) and the wind-up (5.59 ± 2.21 m·s⁻¹). Fastball velocity between the wind-up (36.98 ± 1.44 m·s⁻¹) and stretch (36.72 ± 1.24 m·s⁻¹) did not achieve statistical significance and had a trivial effect size ($p = 0.21$, $d = .19$). Eccentric

rate of force development did not achieve significance ($p = 0.72$ and $p = 0.06$, respectively) when comparing BCMJ ($780.03 \pm 385.29 \text{ N}\cdot\text{s}$) to SUCMJ ($650.61 \pm 324.42 \text{ N}\cdot\text{s}$) and DUCMJ ($744.54 \pm 363.49 \text{ N}\cdot\text{s}$). A comparison of the SUCMJ and the DUCMJ also revealed no significant difference with $p = 0.29$. Table 4-1 demonstrates findings in this section.

Test re-test reliability (ICC, 3, k) had a value of 0.8287 with a 95% confidence interval (CI) = 0.5524, 0.9340 for the stride leg and 0.7877 (CI: 0.4490, 0.9182) for the drive leg within the ULMJ test. These values fall into the good category for a test re-test reliability.

Table 4-2 lists the Pearson product-moment correlations (r) for the jump tests that were conducted on force plates to the GRFs observed during the wind-up and stretch, and the p -values are listed in Table 4-2 as well. An r -value range of 0.456 ~ 0.59, 0.60 ~ 0.79, and 0.8 ~ 1.0 were moderate, moderately high, and high, respectively. A moderately high association was discovered between DUCMJ height and GRFs in the mediolateral direction of the stride leg during the wind-up ($r = 0.64$, $p < 0.001$). Moderate associations were also found for the BCMJ height to GRFs in the medial lateral direction for the stride leg in the wind-up ($r = 0.48$) and anterior posterior GRFs for the drive leg during the stretch ($r = 0.54$). Both of these relationships achieved a level of significance ($p < 0.05$). Stride leg UCMJ height revealed a moderate relationship with the GRFs in the anterior posterior direction of the drive leg during the stretch and achieved significance ($r = 0.47$, $p < 0.05$).

Wind-up vertical forces of the stride leg demonstrated significance with anterior posterior and vertical forces of the stride leg within the stretch ($r = 0.94$, $p < 0.01$ and $r = 0.61$, $p < 0.001$ respectively). Medial lateral forces within the stride leg during the wind-up had a significant, moderately high association with medial lateral forces of the stride leg in the stretch ($r = 0.60$, $p < 0.01$). Moderate associations and significant findings were observed within the GRFs of the

anterior posterior direction within the stride leg of the wind-up for the vertical force in the stride leg for both the wind-up ($r = 0.58, p < 0.01$), stretch ($r = 0.52, p < 0.05$), and a $p < 0.01$ for the anterior posterior direction of the stride leg from the stretch ($r = 0.59$). Stride leg forces during the stretch in the anterior posterior direction had a $p < 0.01$ and a moderate association ($r = 0.56$) for the vertical forces in the stride leg during the stretch.

Anterior posterior directional forces within the drive leg of the wind-up did demonstrate significance in the drive leg during the wind-up in the medial lateral ($r = 0.47, p < 0.05$), vertical ($r = 0.88, p < 0.001$), and for the stretch in the anterior posterior ($r = 0.73, p < 0.001$) and vertical forces ($r = 0.63, p < 0.01$). Drive leg medial lateral forces within the wind-up has revealed a significance of $p < 0.001$ with a moderately high association ($r = 0.76$) for the drive leg in the medial lateral direction during the stretch. A $p < 0.05$ with moderate ($r = 0.52$) and $p < 0.001$ with moderately high associations ($r = 0.68$) respectively were seen in the drive leg vertical forces for the wind-up when compared to anterior posterior and vertical forces in the drive leg during the stretch. Drive leg forces within the anterior posterior during the stretch had a $p < 0.001$ and moderately high association ($r = 0.78$) for the vertical forces within the drive leg during the stretch.

A Pearson product-moment correlation (r) matrix was created for the GRFs during pitching, the speed of the ball, and the distances achieved in all the jump tests that were recorded within this study. The p -values and r -values of this matrix are presented in table 4-2. The wind-up and stretch fastball velocities were not significantly different from each other ($p = 0.21$). Figure 4-3 indicates the fastball velocity differences between the stretch and wind-up delivery. Fastball velocity from the wind-up did achieve moderately high relationships to the drive leg for the anterior posterior direction for the wind-up and stretch ($r = 0.65$ and $r = 0.67$, respectively).

Both of these relationships achieved a level of significance with $p < 0.01$. Fastball velocity during the stretch also attained a moderately high relationship ($r = 0.69$) for the drive leg within the anterior posterior direction in the stretch, and this relationship had achieved a $p < 0.001$.

Height achieved within the BCMJ reached significantly high associations for SUCMJ height ($p < 0.001$, $r = 0.81$), DUCMJ height ($p < 0.001$, $r = 0.87$), and BBJ distance ($p < 0.001$, $r = 0.84$). A significant high association was seen for SULMJ distance to the DULMJ distance ($p < 0.001$, $r = 0.85$). Moderately high associations that were significant with $p < 0.001$ were seen for SUCMJ height to DUCMJ height ($r = 0.68$) and BBJ distance ($r = 0.70$), and an $r = 0.76$ for DUCMJ height to BBJ distance. Bilateral broad jump distance revealed a significantly ($p < 0.01$) moderately high association for the SULMJ ($r = 0.66$) and DULMJ distance ($r = 0.64$). Significant moderate associations were seen for BCMJ height to SULMJ ($p < 0.05$, $r = 0.51$) and DULMJ distance ($p < .01$, $r = .55$). Stride leg UCMJ height attained significant moderate associations for SULMJ ($p < 0.01$, $r = 0.55$) and DULMJ distance ($p < 0.05$, $r = 0.46$).

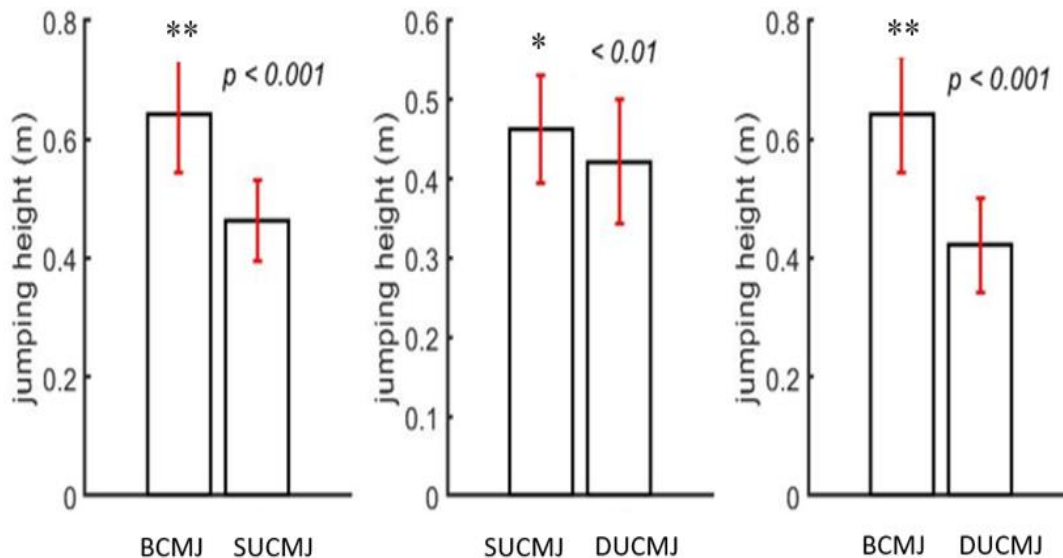


Figure 4-1: BCMJ compared to SUCMJ (left), SUCMJ compared to DUCMJ (middle), and BCMJ compared to DUCMJ (right). * = $p < 0.01$ ** = $p < 0.001$.

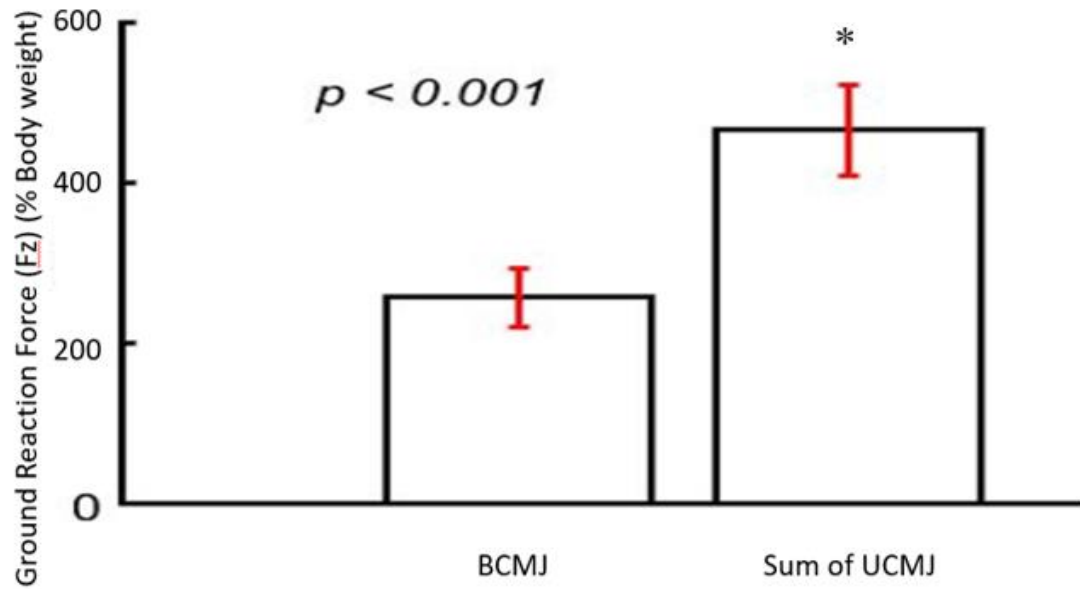


Figure 4-2: Vertical forces produced in the BCMJ (mean: 2.57 ± 0.36 BW) (left) and summation of the DUCMJ and SUCMJ (mean: 4.65 ± 0.56 BW) (right). * = $p < 0.001$.

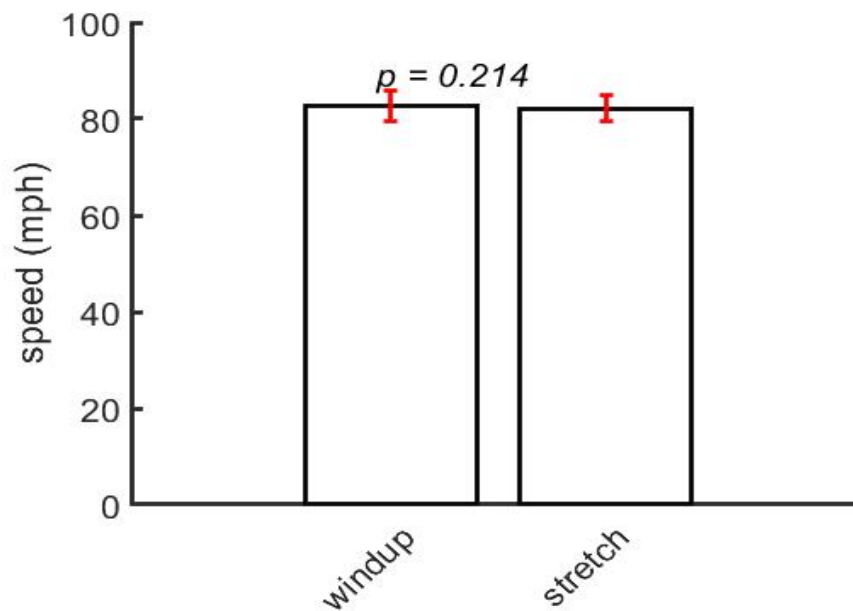


Figure 4-3: Fastball velocity recorded in the lab for the stretch and wind-up delivery.

Table 4-1: Variable statistics *p*-values.

| Variable #1 (Mean \pm SD): | Variable #2 (Mean \pm SD): | <i>p</i>-value: | <i>d</i>: |
|---|---|------------------------|------------------|
| Fastball velocity wind-up (82.72 \pm 3.23 mph) | Fastball velocity stretch (82.14 \pm 2.78 mph) | = 0.21 | 0.19 |
| BCMJ height (.642 \pm .09 m) | SUCMJ height (.463 \pm .07 m) | < 0.001** | 2.22 |
| BCMJ height (.642 \pm .09 m) | DUCMJ height (.422 \pm .08 m) | < 0.001** | 2.58 |
| SUCMJ height (.463 \pm .07 m) | DUCMJ height (.422 \pm .08 m) | < 0.01** | 0.55 |
| Force summation of SUCMJ & DUCMJ (4.65 \pm .56 BW) | BCMJ force (2.57 \pm .36 BW) | < 0.001** | 4.42 |
| DULMJ distance (2.09 \pm .18 m) | SULMJ distance (2.09 \pm .16 m) | = 0.95 | 0 |
| BCMJ absolute peak power (6768.94 \pm 1357.57 W) | SUCMJ absolute peak power (4191.48 \pm 681.86 W) | < 0.001** | 2.40 |
| BCMJ absolute peak power (6768.94 \pm 1357.57 W) | DUCMJ absolute peak power (3819.90 \pm 723.63 W) | < 0.001** | 2.70 |
| SUCMJ absolute peak power (4191.48 \pm 681.86 W) | DUCMJ absolute peak power (3819.90 \pm 723.63 W) | < 0.01** | 0.53 |
| BCMJ normalized peak power by BW (7.67 \pm 1.35 W/kg) | SUCMJ normalized peak power by BW (4.74 \pm .6 W/kg) | < 0.001** | 2.80 |
| BCMJ normalized peak power by BW (7.67 \pm 1.35 W/kg) | DUCMJ normalized peak power by BW (4.34 \pm .75 W/kg) | < 0.001** | 3.05 |
| SUCMJ normalized peak power by BW (4.74 \pm .6 W/kg) | DUCMJ normalized peak power by BW (4.34 \pm .75 W/kg) | < 0.01** | 0.59 |
| BCMJ vertical takeoff velocity (2.49 \pm .42 m·s) | SUCMJ vertical takeoff velocity (1.86 \pm .31 m·s) | < 0.001** | 1.71 |
| BCMJ vertical takeoff velocity (2.49 \pm .42 m·s) | DUCMJ vertical takeoff velocity (1.79 \pm .35 m·s) | < 0.001** | 1.81 |
| SUCMJ vertical takeoff velocity (1.86 \pm .31 m·s) | DUCMJ vertical takeoff velocity (1.79 \pm .35 m·s) | = 0.22 | 0.21 |
| BCMJ concentric impulse (-593 \pm 192 N·s) | SUCMJ concentric impulse (-527 \pm 138 N·s) | < 0.05* | 0.39 |
| BCMJ concentric impulse (-593 \pm 192 N·s) | DUCMJ concentric impulse (-533 \pm 111 N·s) | < 0.05* | 0.38 |
| SUCMJ concentric impulse (-527 \pm 138 N·s) | DUCMJ concentric impulse (-533 \pm 111 N·s) | = 0.69 | 0.05 |
| BCMJ RSImod (1.18 \pm 0.4 m·s) | SUCMJ RSImod (1.27 \pm 0.39 m·s) | = 0.06 | 0.23 |
| BCMJ RSImod (1.18 \pm 0.4 m·s) | DUCMJ RSImod (1.36 \pm 0.41 m·s) | = 0.17 | 0.44 |
| SUCMJ RSImod (1.27 \pm 0.39 m·s) | DUCMJ RSImod (1.36 \pm 0.41 m·s) | = 0.34 | 0.22 |

| | | | |
|---|---|--------|------|
| Peak propulsion acceleration anterior posterior stretch (6.09 ± 0.32 m·s) | Peak propulsion acceleration anterior posterior wind-up (5.59 ± 2.21 m·s) | = 0.24 | 0.32 |
| BCMJ EccRFD (780.03 ± 385.29 N·s) | SUCMJ EccRFD (650.61 ± 324.42 N·s) | = 0.72 | 0.36 |
| BCMJ EccRFD (780.03 ± 385.29 N·s) | DUCMJ EccRFD (744.54 ± 363.49 N·s) | = 0.06 | 0.09 |
| SUCMJ EccRFD (650.61 ± 324.42 N·s) | DUCMJ EccRFD (744.54 ± 363.49 N·s) | = 0.29 | 0.09 |

BCMJ= Bilateral countermovement jump, SUCMJ= stride leg unilateral countermovement jump, DUCMJ= drive leg unilateral countermovement jump, SULMJ= stride leg unilateral lateral to medial jump, DULMJ= drive leg unilateral lateral to medial jump, BW= body weight, RSImod= reactive strength index modified, EccRFD=eccentric rate of force development, * = $p < 0.05$, ** = $p < 0.01$, ***= $p < 0.001$.

Table 4-2: Correlations between pitching GRFs, jumps GRFs, jump distance/height, and fastball velocity.

| Variable #1: | Variable #2: | r-value: | p-value: |
|--|--|----------|------------|
| Mediolateral forces of the stride leg during the wind-up | Vertical forces of the stride leg from the stretch | 0.95 | < 0.001*** |
| Anterior posterior forces of the drive leg in the wind-up | Vertical forces of the drive leg in the wind-up | 0.89 | < 0.001*** |
| | SUCMJ height | 0.81 | < 0.001*** |
| BCMJJ height | DUCMJ height | 0.87 | < 0.001*** |
| | BBJ distance | 0.84 | < 0.001*** |
| SULMJ distance | DULMJ distance | 0.85 | < 0.001*** |
| BCMJJ height | SUCMJ height | 0.74 | < 0.001*** |
| | DUCMJ height | 0.71 | < 0.001*** |
| SUCMJ height | DUCMJ height | 0.66 | < 0.01** |
| DUCMJ height | Mediolateral forces of the stride leg in the wind-up | 0.64 | < 0.01** |
| Mediolateral forces of the stride leg in the wind-up | Mediolateral forces of the stride leg in the stretch | 0.60 | < 0.01** |
| Vertical forces of the stride leg in the wind-up | Anterior posterior forces of the stride leg in the stretch | 0.62 | < 0.01** |
| Anterior posterior forces of the drive leg in the wind-up | Anterior posterior forces of the drive leg in the stretch | 0.74 | < 0.001*** |
| Vertical forces of the drive leg in the wind-up | Vertical forces of the drive leg in the stretch | 0.68 | < 0.01** |
| Anterior posterior forces of the drive leg in the stretch | Vertical forces of the drive leg in the stretch | 0.78 | < 0.001*** |
| | Fastball stretch velocity | 0.79 | < 0.001*** |
| Fastball wind-up velocity | Anterior posterior forces of the drive leg in the wind-up | 0.65 | < 0.01** |
| | Anterior posterior forces of the drive leg in the stretch | 0.67 | < 0.01** |
| Fastball stretch velocity | Anterior posterior forces of the drive leg in the stretch | 0.69 | < 0.001*** |
| Anterior posterior forces of the drive leg in the wind-up | Anterior posterior forces of the drive leg in the stretch | 0.74 | < 0.001*** |
| Anterior posterior forces of the stride leg in the wind-up | Anterior posterior forces of the stride leg in the stretch | 0.60 | < 0.01** |
| | DUCMJ height | 0.68 | < 0.001*** |
| SUCMJ height | BBJ distance | 0.70 | < 0.001*** |
| DUCMJ height | BBJ distance | 0.76 | < 0.001*** |

| | | | |
|--|--|------|----------|
| BBJ distance | SULMJ distance | 0.66 | < 0.01** |
| | DULMJ distance | 0.64 | < 0.01** |
| BCMJ height | Mediolateral forces of the stride leg in the wind-up | 0.48 | < 0.05* |
| | Anterior posterior forces of the drive leg in the stretch | 0.54 | < 0.05* |
| SUCMJ | Anterior posterior forces of the drive leg in the stretch | 0.47 | < 0.05* |
| | Vertical forces of the stride leg in the wind-up | 0.58 | < 0.01** |
| Anterior posterior forces of the stride leg in the wind-up | Anterior posterior forces of the stride leg in the stretch | 0.59 | < 0.01** |
| | Vertical forces of the stride leg in the stretch | 0.52 | < 0.01** |
| Anterior posterior forces of the drive leg in the wind-up | Mediolateral forces of the drive leg in the wind-up | 0.47 | < 0.05* |
| Vertical forces of the drive leg in the wind-up | Anterior posterior forces of the drive leg in the stretch | 0.52 | < 0.05* |
| Anterior posterior forces of the stride leg in the stretch | Vertical forces of the stride leg in the stretch | 0.56 | < 0.01** |
| BCMJ height | SULMJ distance | 0.51 | < 0.05* |
| | DULMJ distance | 0.55 | < 0.01** |
| SUCMJ height | SULMJ distance | 0.55 | < 0.01** |
| | DULMJ distance | 0.46 | < 0.05* |

BCMJ= Bilateral countermovement jump, SUCMJ= stride leg unilateral countermovement jump, DUCMJ= drive leg unilateral countermovement jump, SULMJ= stride leg unilateral lateral to medial jump, DULMJ= drive leg unilateral lateral to medial jump, BBJ= bilateral broad jump, high association = 0.8 ~ 1.0, moderately high association = 0.6 ~ 0.79, moderate association = 0.456 ~ 0.59, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

CHAPTER 5

DISCUSSION

This study's purpose was to assess a possible relationship amongst UCMJ, BCMJ, BBJ, and ULMJ distance on multicomponent GRFs and their influence on stride leg and drive leg profiles during the wind-up and stretch deliveries in baseball pitching. Another aim was to assess a relationship of estimated peak power in the BBJ and ULMJ distance to GRFs in pitching. Lastly, it was expected that all jump distances would correlate to fastball velocity. The results from this study did not support any of the hypotheses. None of the jump tests demonstrated any significant influence within the drive leg and stride leg GRFs in either the wind-up or stretch. Bilateral broad jump and ULMJ failed to reach significance for GRFs within the anterior posterior direction during pitching, which should indicate a pitcher's ability to produce lower body power/force in the intended direction. However, significant intercorrelations between jumps were found, therefore it would be prudent to incorporate a variety of jump tests into a baseball pitcher's testing schedule as they contribute to the total amount of direction-specific power that the athlete can produce.

A variable of interest that demonstrated an unusual finding was SUCMJ was significantly greater than the DUCMJ. This is unexpected as a dominate leg (drive leg) would be thought to typically be able to produce more force and demonstrate more coordination than the non-dominant leg (stride leg). Matsuo et al. (2001) and Campbell et al. (2010) did suggest that strength of the stride leg helps with bracing, therefore the constant number of stride foot contacts from repetitive pitching could have resulted in the stride leg (non-dominant leg) getting stronger over the course of a pitcher's career by absorbing high linear momentum and the effect of gravity

going into foot plant (Ramsey & Crotin, 2016, 2019) Given this background, the higher force tendencies seen for the stride leg could be the reason why Division I collegiate baseball pitchers were able to jump higher off their stride leg than their drive leg.

Bilateral countermovement vertical jump height was significantly greater than DUCMJ and SUCMJ height. However, the total amount of force produced by the SUCMJ and DUCMJ combined was significantly greater than the BCMJ alone. An extension of these findings can be seen in evaluating the bilateral index %, as a value of -27.24% was seen between participants BCMJ and their UCMJ height. This difference illustrates that Division I collegiate baseball pitchers are more single leg dominant. This finding was not unique to sports performance research as Vandervoort et al. (1984) found that maximal isometric and concentric strength of both quadriceps were significantly lower than the summation of single leg quadricep maximal isometric and concentric strength that could indicate lowered force production bilaterally than the sum of single strength. Although the muscles were isolated onto a specific machine, the current jump study reflects that there could be a potential activation deficit within a dynamic muscle action in jumping. These authors mentioned that the differences between single leg and double leg strengths were attributed to reduced fast twitch motor unit activation via reduced voluntary drive. A human musculoskeletal model and 8 active males demonstrated 20% less work of the right leg in a bilateral squat jump than a single leg squat jump, with both jumps not involving a countermovement (Bobbert et al., 2006). Within the model, the authors found that 75% of the bilateral deficit was explained by a faster shortening velocity within the BCMJ, while the remaining percentage could be explained by lower muscular activation. Therefore, they suggested the bilateral deficit is due to the force-velocity relationship and not exclusively a decrease in neural drive. A possible theory could be that the drive leg will only be able to

produce as much force that the stride leg could absorb, therefore it may be wise to focus training on stride leg (non-dominant leg) force absorption (eccentric) exercises. These findings between bilateral and unilateral jumping should be considered to help sport performance staff design and implement training methodologies to account for lateral differences in power between both legs.

Unilateral lateral to medial jump distances between the drive leg and stride leg were similar and not statistically different from one another in the current study. This is an interesting finding as the drive leg did not perform any better than the stride leg. A possible explanation for this is the stride leg's interaction in the delivery is more forceful, which could be responsible for equalizing ULMJ distances despite the athlete initiating the delivery with the drive leg. In a previous study, Lehman et al. (2013) found that ULMJ of the drive leg was the best predictor of ball speed within collegiate baseball players throwing from flat ground. An important note about the Lehman et al. (2013) study, is that the participants, which were position players and pitchers, were on average 7 kg lighter than the participants involved within the current study. Different methodologies and subjects were used to measure throwing and fastball pitching velocities in their study and in the current study. Studies looking at cricket players have found that stride leg isometric hip abduction strength had a significant relationship to throwing velocity (Ahmed et al., 2020), as well as ULMJ of the drive leg (Freeston et al., 2016). It is important to note that baseball and cricket throwing mechanics are considered to be different to substantiate why the results were not similar. Both SULMJ and DULMJ achieved a significant difference in distance achieved when compared to BCMJ height, SUCMJ height, and BBJ distances. These significant differences could be due to the ULMJ being a sport specific activity, as well as it being easier to displace the center of mass horizontally than vertically (Freeston et al., 2016; Lehman et al., 2013). Bilateral broad jump distance also achieved significantly greater distance when compared

to BCMJ, SUCMJ, and DUCMJ height. Throwing velocity has been linked to BBJ distance within baseball and handball players (Nakata et al., 2013; Zapartidis et al., 2009, 2011); however, this evidence has not been observed within collegiate baseball players (Lehman et al., 2013) or pitchers (Szymanski et al., 2020). The significant differences seen may be due to the limited times a baseball player performs a vertical jump during the game of baseball. It is important to note that some athletes may be better in various directions based on previous sport backgrounds, as some of the correlations were only moderately high between each jump test.

Absolute peak power, peak power normalized by body weight, and vertical takeoff velocity achieved significance when comparing the BCMJ to SUCMJ and DUCMJ. These variables could play a role as to why the BCMJ achieved significance in height when compared to SUCMJ and DUCMJ. Stride leg UCMJ did achieve significantly greater absolute peak power and peak power normalized by body weight compared to DUCMJ, but no differences were observed for vertical takeoff velocity. These variables were significantly greater in the SUCMJ and could be the reason as to why participants achieved significantly greater height when compared to their DUCMJ. Concentric impulse, RSImod, and EccRFD resulted in no significant differences between the BCMJ, SUCMJ, and DUCMJ. These variables not achieving significance is possibly due to the same time constraint that is involved within the formula for each variable. A trend was observed towards greater values bilaterally which may result in significance in future studies with larger sample sizes, which could influence jump power measures. Turner et al. (2020) has mentioned that power production is completed within a short timeframe of < 0.3 seconds. Differences amongst wind-up and stretch deliveries has rarely been researched within the literature, so the rationale behind no significance occurring for peak

propulsion acceleration of the two delivery methods, is likely due to nonsignificant differences in peak center of mass acceleration.

Relationships amongst jump GRFs and pitch GRFs revealed an interesting occurrence. Unilateral countermovement vertical jumps had achieved associations for the contralateral leg that is involved during pitching. This indicates that force production on one side of the body can impact force production on the other side of the body that are direction specific. Drive leg UCMJ height produced significant, moderately high associations with the mediolateral forces for the stride leg during the wind-up, while the SUCMJ height revealed significant, moderate correlation with the anterior posterior forces for the drive leg within the stretch. Bilateral countermovement vertical jump height did achieve a significantly moderate relationship to mediolateral forces for the stride leg in the wind-up and anterior posterior forces for the drive leg during the stretch. To the author's knowledge there is not a study assessing the relationship between jump height to GRFs to either the drive leg or stride leg GRFs during pitching. Therefore, it is suggested that more research is required to develop a better understanding of these findings in other competitive levels that may show inconsistency across professional, high school, or youth baseball ranks.

Ground reaction forces, specifically for the stride leg, revealed associations for the stretch delivery and limited findings with the wind-up. Vertical forces for the stride leg in the wind-up had significantly high and moderately high associations for the anterior posterior and vertical forces for the stride leg during the stretch, respectively. Wind-up mediolateral forces showed significant, moderately high associations for the stride leg between wind-up and the stretch. This reveals that no matter what delivery was performed, a pitcher will have similar mediolateral, stride leg forces. Wind-up stride leg anterior posterior forces showed a significant, moderate association with vertical stride leg forces in both deliveries, as well as anterior posterior forces of

the stride leg during the stretch. Lastly, anterior posterior forces for the stride leg in the stretch had a significant, moderate relationship to stride leg vertical forces in the stretch. This indicates that both GRF vectors are related in stride leg bracing within stretch deliveries.

Analysis of the drive leg GRFs showed a mixture of findings between delivery types. Wind-up anterior posterior forces for the drive leg had moderate and high associations respectively for drive leg mediolateral and vertical forces in the wind-up, and moderately high significant relationships for the anterior posterior and vertical forces in the stretch. In the wind-up and stretch, ipsilateral triaxial force production for the drive leg appears to be constant between deliveries, as a moderately high significant relationship was seen within mediolateral forces for the drive leg in the wind-up to mediolateral forces of the drive leg in the stretch. This shows that mediolateral forces in either delivery method are similar in the drive leg. Vertical drive leg forces during the wind-up had significant, moderate and moderately high associations respectively for drive leg anterior posterior and vertical forces in the stretch. Another drive leg finding revealed a moderately high significant relationship between anterior posterior forces in the stretch and vertical GRFs for the drive leg in the stretch. Minimal research has been conducted on correlating GRF between deliveries. From this study, it can be deduced that stretch and wind-up deliveries are closely related as an athlete's motor development may closely unite GRF applications for the lower body.

Wind-up fastball velocity achieved a moderately high, significant relationship for the drive leg anterior posterior forces between the wind-up and stretch. Stretch fastball velocities attained a significant, moderately high relationship with drive leg anterior posterior forces for the stretch. Theoretically these findings could demonstrate that the drive leg GRFs is an important contributor to ball velocity from the stretch or the wind-up. Since the drive leg has a significant

relationship, future studies should assess ULMJ GRFs to pitching GRFs as it mimics the actions of the drive leg during pitching.

In terms of practical application, jump tests that were recorded on force plates did not reveal any significant findings of interest with fastball velocity. However, this study has demonstrated that collegiate pitchers are significantly more powerful vertically with their stride leg than their drive leg. This finding could be due to the stride leg being required to absorb the propulsion forces from the drive leg. Therefore, a training program may want to incorporate more eccentric/force absorption exercises of the stride leg. It would still be important to train the drive leg as it did perform significantly lower when compared to the SUCMJ for absolute peak power and normalized peak power by body weight. A contralateral effect was seen within the opposite legs during UCMJ tests and the drive or stride leg GRFs when pitching (drive leg UCMJ height was correlated to stride leg GRFs, while stride leg UCMJ height was correlated to drive leg GRFs), so it would be prudent to train the opposing leg as well. Forces within both deliveries were similar, so improving force in one delivery should carry over into the other. Drive leg anterior posterior forces were related to fastball velocity. This result should influence coaches to include frontal plane exercises to increase the amount of force produced within the drive leg to possibly increase fastball velocity. Division I collegiate pitchers within this study revealed that they are more unilateral dominant than bilateral dominant. This information suggests implementing more unilateral training than bilateral training in order to possibly increase the amount of force produced within one leg.

CHAPTER 6

CONCLUSION

Jump tests (BCMJs, SUCMJ, and DUCMJ) GRFs revealed no significant relationships between the GRFs observed during a wind-up or stretch while pitching. Other jump tests that were conducted also revealed no significant relationships to pitching performance. However, the researchers of this study believe it is still important to incorporate multidirectional jump tests as they will provide information about the athlete's ability to produce power within multiple planes. Training should involve all variations of jumps to improve their performance within multiple directions. Contralateral effects were observed between jump performances of one leg and the GRFs of the other leg. Participant's stride leg UCMJ height was significantly higher than their DUCMJ height. This information could create a theory that pitchers with greater differences between combined unilateral jumping height and bilateral jumping height, which is referred to as bilateral index (Bogdanis et al., 2019), may be more effective, as pitching is done primarily unilaterally in the frontal plane towards home plate. Ground reaction forces within the stretch and wind-up were similar, therefore improving force in either delivery should improve force production unanimously. Fastball velocity was associated with drive leg GRFs in the anterior posterior direction (toward home plate); however, there was no relationship between DULMJ and fastball velocity. Based on this study, it is recommended to incorporate training unilaterally to possibly contribute to greater GRFs contralaterally, which can be accomplished by performing plyometric movements in the frontal plane, as well as incorporate single leg maximum vertical

jumps which will increase the bilateral deficit, and thereby enhance anterior posterior GRFs (towards home plate) of the drive leg.

6.1 Limitations

A limitation that could have impacted this study was that mean fastball velocity recorded in the Sport and Movement Science Laboratory at Louisiana Tech University was on average 6% slower than fastball velocity recorded during intrasquad games play at the field with the same ball tracking device. A likely reason for this difference could be a reduction of adrenaline due to the testing environment not being competitive in nature. Another reason for the differences is that during testing, the initial participants, at times, slipped during stride foot contact with the front force plate embedded in the custom-built mound due to the type of shoe worn during data collection. To remedy the situation, pitchers were informed to wear a baseball turf or basketball shoe instead of running shoe that had a different type of sole than a running shoe, and a spray adhesive was applied to the front force plate to reduce stride foot slipping. A future solution is to apply a turf surface over the force plates so that the player's shoes do not slip.

6.2 Future Research

Pitching within the sport of baseball can be a critical component to winning games. A major concern with pitchers is the chance of developing an injury to their throwing arm, thus ruling them out for the season. Injuries within pitchers is a growing trend over the past couple of decades (Conte et al., 2001, 2016; Escamilla et al., 2018; Mayberry et al., 2020). Overuse is the likely culprit as throwing arm injuries most often require a lengthy surgical and rehab process. An efficient kinetic chain, which is defined as an integration of body segment activation and motion (Kibler & Sciascia, 2004), is believed to lessen effort of the throwing arm in producing high

velocity. As result, it is very important for a pitcher to learn how to use their lower body as the major producer of force that contributes to ball velocities in addition to their upper extremities (Kibler et al., 2013; Kibler & Sciascia, 2004). Therefore, a future direction with this research is to assess the relationship of fastball velocity GRFs and injury rates.

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APPENDICES

Appendix A: IRB Approval Letter



OFFICE OF SPONSORED PROJECTS

TO: Dr. David Szymanski

FROM: Dr. Richard Kordal, Director of Intellectual Property & Commercialization (OIPC)
rkordal@latech.edu *RSR*

SUBJECT: HUMAN USE COMMITTEE REVIEW

DATE: July 30, 2019

In order to facilitate your project, an EXPEDITED REVIEW has been done for your proposed study entitled:

“Physiological and Anthropometric Characteristics of Division 1 College Baseball Players over an Entire Year”

HUC 20-006

The proposed study's revised procedures were found to provide reasonable and adequate safeguards against possible risks involving human subjects. The information to be collected may be personal in nature or implication. Therefore, diligent care needs to be taken to protect the privacy of the participants and to assure that the data are kept confidential. Informed consent is a critical part of the research process. The subjects must be informed that their participation is voluntary. It is important that consent materials be presented in a language understandable to every participant. If you have participants in your study whose first language is not English, be sure that informed consent materials are adequately explained or translated. Since your reviewed project appears to do no damage to the participants, the Human Use Committee grants approval of the involvement of human subjects as outlined.

Projects should be renewed annually. *This approval was finalized on July 30, 2019 and this project will need to receive a continuation review by the IRB if the project continues beyond July 30, 2020. ANY CHANGES* to your protocol procedures, including minor changes, should be reported immediately to the IRB for approval before implementation. Projects involving NIH funds require annual education training to be documented. For more information regarding this, contact the Office of Sponsored Projects.

You are requested to maintain written records of your procedures, data collected, and subjects involved. These records will need to be available upon request during the conduct of the study and retained by the university for three years after the conclusion of the study. If changes occur in recruiting of subjects, informed consent process or in your research protocol, or if unanticipated problems should arise it is the Researchers responsibility to notify the Office of Sponsored Projects or IRB in writing. The project should be discontinued until modifications can be reviewed and approved.

Please be aware that you are responsible for reporting any adverse events or unanticipated problems.

A MEMBER OF THE UNIVERSITY OF LOUISIANA SYSTEM

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Appendix B

HUMAN SUBJECTS CONSENT FORM

The following is a brief summary of the project in which you are asked to participate. Please read this information before signing the statement below. You must be of legal age or must be co-signed by parent or guardian to participate in this study.

TITLE OF PROJECT: Physiological and anthropometric characteristics of Division I college baseball players over an entire year

PURPOSE OF STUDY/PROJECT: Recently, there have been some studies which have investigated the physiological and anthropometric characteristics of basketball and rugby athletes. Studies of the physiological and anthropometric characteristics of baseball players are uncommon. To date, there has been only one study that has characterized these variables throughout an entire competitive baseball season. Therefore, the purpose of this study is to assess the physiological and anthropometric characteristics of Division I college baseball players over an entire year and to determine any relationships to offensive and defensive performance.

SUBJECTS: Because you are a Louisiana Tech men's baseball players, you are being invited to participate in this study. If you choose to participate and give your informed consent, you will be asked to test 4 times. Testing sessions will occur in September (off-season), December (preseason), March (midseason), and May (end-season).

PROCEDURE: During the initial session (team's first meeting), the research study will be verbally explained by the Project Director to you and you will answer a modified Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) to assess your general health. If you progress through this initial PAR-Q+ screening and are approved to participate in athletics from the LaTech Medical and Athletic Training Staff, you will complete a Descriptive Data Questionnaire which will allow you to list your age and describe your baseball playing and exercising experiences.

In September (off-season), you will meet in Scotty Robertson Memorial Gym to be assessed over two weeks. Three testing stations during weeks 1 and 2 of the off-season (September) as well as 2 weeks during the preseason (December), midseason (March), and end-season (May) will occur in the Applied Physiology Lab, Memorial Gym basketball court, and Sport & Movement Science Lab.

The procedures for testing will be verbally explained by the Project Director to you before testing begins in September 2019. A total testing time for players on each day will

maximally take 4 hours per day; however, each player's testing time will not take more than a maximum of 60 minutes per day. Stations representing each test will be set up around Scotty Robertson Memorial Gym. When appropriate, you will perform an active, dynamic warm-up for 15 minutes before active performance testing. Once this has been completed, you will be assigned to one of three groups and rotate to the various stations on a given day until all are completed.

During week 1 in the Applied Physiology Lab, you will have height, body mass, body composition, hydration status, grip strength, leg-low back strength measured. On the Memorial Gym basketball court, you will complete the 20-meter Pacer test, which will estimate your VO_2max . Against the north wall of Memorial Gym you will complete a medicine ball throw. In the Sport & Movement Science Lab, you will perform 2-leg and 1-leg vertical jump tests from force plates while using a jumping (Vertec) device. You will also perform a 2-leg standing long jump test for distance and to estimate peak power and 1-leg lateral to medial jump for distance. You will also have your vision tested by Vizual Edge computerized software.

During week 2 in the Applied Physiology Lab, you will perform three different isokinetic tests to assess your throwing and non-throwing shoulder force production on the Biodex isokinetic device. The first test will be the internal and external rotation at 90° . The second test will be an internal and external rotation at a modified 0° . The third test will be the diagonal 2 pattern flexion and extension. You will perform three different isokinetic tests to assess throwing and non-throwing lower arm force production on the Biodex isokinetic device. The first test will be the wrist flexion and extension. The second test will be forearm pronation and supination. The third test will be elbow flexion and extension. All of these tests measures force output at a specific speed (degrees per second) and range of motion. Also in the Applied Physiology Lab, you will perform a treadmill VO_2max test which measures the maximal amount of oxygen utilized by the body while running to failure. In the Sport & Movement Science Lab, you will pitch from a custom-made pitcher's mound that is 60'6" from home plate. The mound will have two Bertec force plates embedded in it. Ground reaction forces, peak power, and other variables will be recorded. A 12-camera motion capture analysis system will be used to record your throwing mechanics while pitching from a custom-made pitching mound with two force plates. A Rapsodo device will be used to measure throwing velocity, spin rate, spin efficiency, pitch break, spin axis, and release point. You will wear a CosMed K5 portable metabolic unit while pitching to record oxygen consumption. Bat velocity and launch angle will be recorded with a Blast motion sensor while batted-ball exit velocity will be measured with a Pocket Radar device. You will be re-assessed using the same tests, equipment, and procedures described above during the preseason (December), midseason (March), and end-season (May).

BENEFITS/COMPENSATION: At the end of this study, you will receive a Baseball Player Profile Report, which will include information about your physical fitness level and baseball performance skills. Also, you will learn how team health and skill performance data relates to offensive and defensive baseball performance. No

compensation will be provided; however, you will receive a copy of the abstract upon request after the project.

RISKS, DISCOMFORTS, ALTERNATIVE TREATMENTS: You understand that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research. However, since you are a university athlete, you will have access to the medical and athletic training staff if an injury occurs. All tests and baseball-specific activities involved in this study present minimal risks to you, and are very similar to what you would normally experience during college baseball team practices/games. You might experience soreness. Muscle/tendon strains or soreness and ligament sprains due to near-maximal effort bat swings, pitching/throwing, and performance activities may occur. Since these protocols are typical of the daily activities during practice or games, there is little risk. Risk of injury will also be significantly reduced due to the warm-up before testing, close adult supervision, proper instruction, and a well-designed study. A very similar study to this one was conducted with the 2009 LaTech Baseball team without any injuries to the players by the same Project Director. You will be screened for health and medical risks. Specifically, you will be asked if you have had a muscle/tendon strain or ligament sprain before. If you have had an injury within the last month, you will not be able to participate. You will be considered free from injury in the lower and upper extremities if you make it through the LaTech Athletic Training/Medical Staff and PAR-Q+ health and medical screenings.

The risks associated with an exercise treadmill (VO_2max) test, such as fatigue, muscle soreness, irregular heartbeat, chest pain, and sudden heart attack, are about the same as those that may happen during strenuous athletic events. Severe irregular heartbeat, heart attacks, stroke, or death are extremely rare in adults with a normal, low-risk health history. To minimize these risks you will be screened by the LaTech Athletic Training and Medical Staff as well as the PAR-Q+ health and medical questionnaire. Furthermore, a trained exercise physiologist (Project Director) will perform this procedure. This test is routinely performed in the Applied Physiology Lab with Kinesiology students in exercise prescription classes without any complications. Also, you will have your heart rate and rating of perceived exertion monitored continuously throughout the test. The test will be discontinued if any abnormal heart rate or rhythm is detected. Emergency equipment (Automated External Defibrillator) in the Applied Physiology Lab and trained personnel are available to deal with unusual situations which may arise.

You understand that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research.

The following disclosure applies to all participants using online survey tools:
This server may collect information and your IP address indirectly and automatically via “cookies.”

I, _____, attest with my signature that I have read and understood the following description of the study, "Physiological and anthropometric characteristics of Division I college baseball players over an entire year", and its purposes and methods. I understand that my participation in this research is strictly voluntary and my participation or refusal to participate in this study will not affect my relationship with Louisiana Tech University, the Baseball team, or my grades in any way. Further, I understand that I may withdraw at any time or refuse to answer any questions without penalty. Upon completion of the study, I understand that the results will be freely available to me upon request. I understand that the results of the material will be confidential, accessible only to the principal investigators, myself, or a legally appointed representative. I have not been requested to waive, nor do I waive any of my rights related to participating in this study.

Signature of Participant _____ Date _____

CONTACT INFORMATION: The principal experimenters listed below may be reached to

Answer questions about the research, subjects' rights, or related matters.

PRINCIPAL INVESTIGATORS: David J. Szymanski, dszyman@latech.edu, 318-257-4432;

CO-INVESTIGATOR: Mu Qiao, mqiao@latech.edu, 318-257-5467

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters:

Dr. Richard Kordal
Director, Office of Intellectual Property & Commercialization
Ph: (318) 257-2484
Email: rkordal@latech.edu